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EP 1271172 A2
US 5576623 A
US 5200701 A
US 20030016015 A1
US 5729141 A
US 5414360 A
US 4636729 A

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(54) Abstract Title: **GRADIENT COIL SYSTEM**

(57) The present application discloses a gradient-coil system including the following features:

- at least two structurally independent units which contain at least the partial coils of the gradient coils of the gradient-coil system, and
- a support in which the units are secured, spaced from one another, for an antenna system which is capable of being arranged between them.

A magnetic-resonance apparatus incorporating the gradient-coil system is also disclosed.

FIG 1

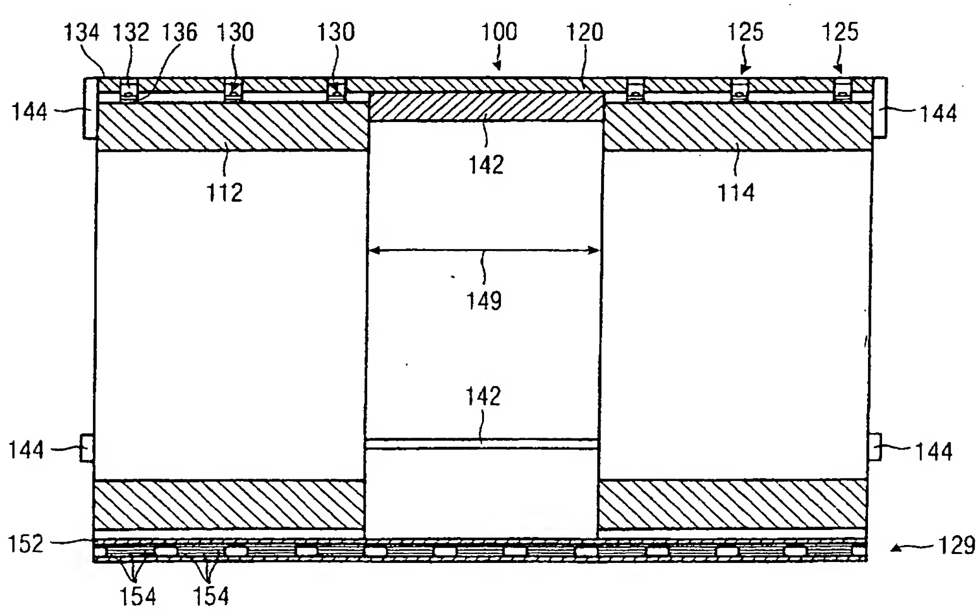

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FIG 1

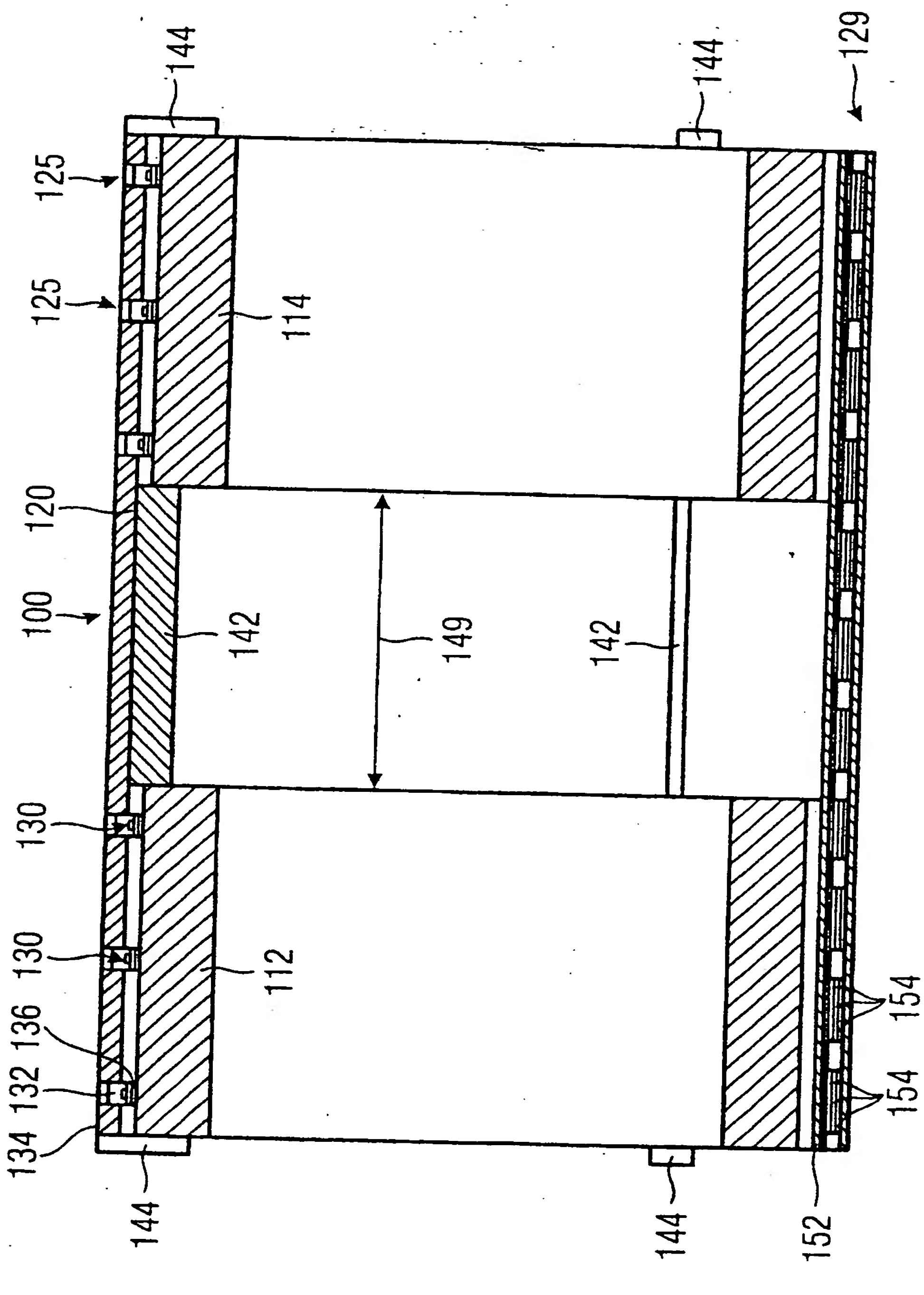
144
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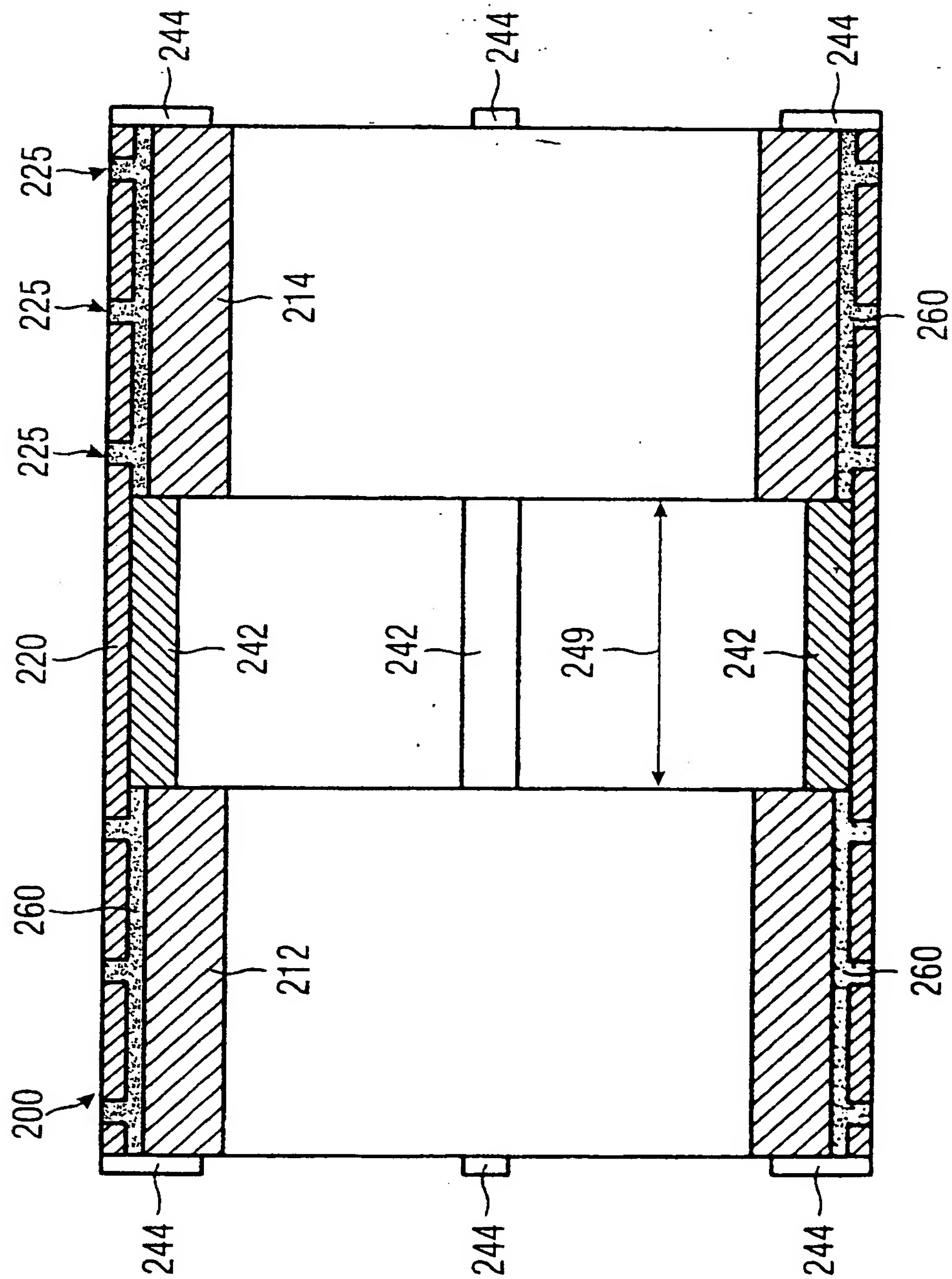
FIG 2



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212
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200
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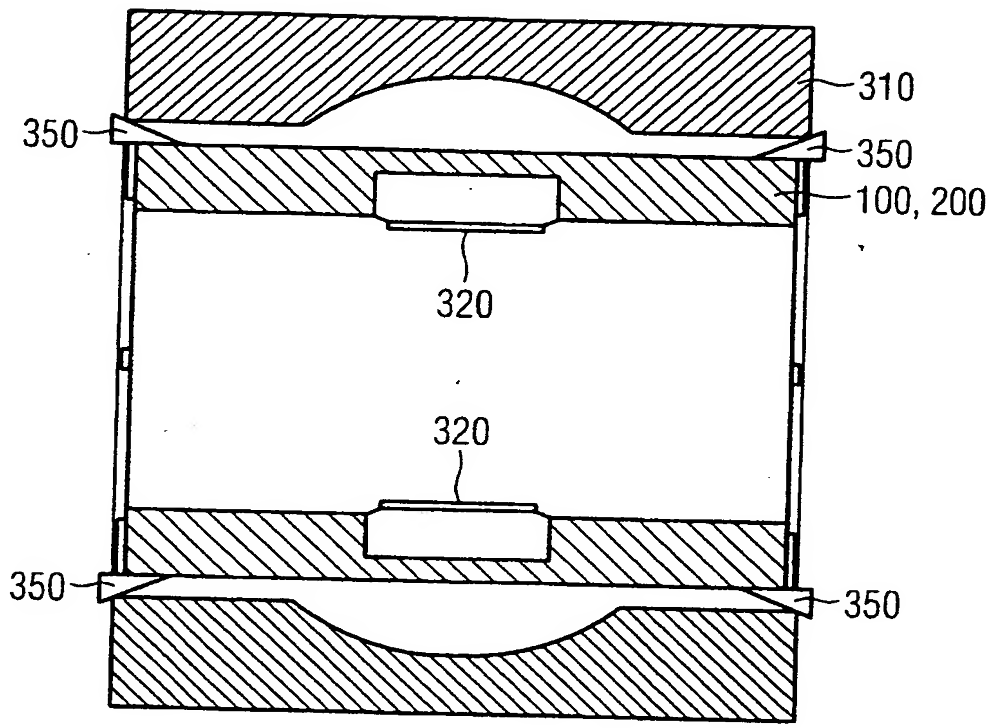
244

FIG 3



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Gradient-coil system and magnetic-resonance apparatus incorporating the gradient-coil system

The invention relates to a gradient-coil system and to a magnetic-resonance apparatus incorporating the gradient-coil system.

Magnetic-resonance technology is a known technology for, inter alia, obtaining images of the interior of the body of an object under examination. In this connection, rapidly switched gradient fields which are generated by a gradient-coil system are superimposed in a magnetic-resonance apparatus on a static uniform magnetic field which is generated by a main field magnet. The magnetic-resonance apparatus further comprises a high-frequency system which beams high-frequency signals into the object under examination with a view to triggering magnetic-resonance signals and which receives the triggered magnetic-resonance signals, on the basis of which magnetic-resonance images are created.
A structure of a hollow cylindrical gradient-coil system with screening coils is presented in DE 197 22 221 A1, for example. In this case the gradient-coil system comprises, from the inside to the outside, the following elements, which are formed in hollow cylindrical regions arranged concentrically in relation to one another: a first transverse gradient coil, a second transverse gradient coil, a first cooling device, a longitudinal gradient coil, a shim assembly, a second cooling device, a longitudinal screening coil, a first transverse screening coil and a second transverse screening coil. The aforementioned elements are potted in one processing step so as to form the gradient-coil system.

With a view to generating gradient fields, appropriate currents have to be adjusted in gradient coils of the gradient-coil system. In this connection, the

amplitudes of the requisite currents amount to up to several 100 A. The rates of rise and fall of the current amount to up to several 100 kA/s. Given an existing uniform magnetic field in the order of 1 T, Lorentz forces act on these temporally varying currents in the gradient coils, which result in vibrations of the gradient-coil system. These vibrations are passed on to the surface of the magnetic-resonance apparatus via various propagation paths. The mechanical vibrations are converted there into acoustic oscillations which ultimately result in noise, in itself undesirable.

From DE 197 22 481 A1 a magnetic-resonance apparatus is known in which a main field magnet has a first face and a gradient-coil system has a second face, the two faces which are turned towards one another being spaced from one another, and a noise-reducing device for damping the vibrations of the gradient-coil system and/or for reinforcing the gradient-coil system being arranged in contact with the two faces. In one embodiment, the noise-reducing device comprises appropriate seals for the purpose of forming a closed, sealed space between the two faces, said space being filled with sand, foam, a pressurised liquid or other vibration-damping and/or reinforcing substances. In another embodiment, the noise-reducing device comprises several cushions which may be filled with one of the aforementioned substances. In yet another embodiment, in a main field magnet exhibiting a cylindrical cavity in which a hollow cylindrical gradient-coil system is arranged, the noise-reducing device is constituted by wedges which are inserted between the two faces.

Furthermore, from DE 101 56 770 A1 a magnetic-resonance apparatus incorporating a gradient-coil system is known in which an electrically conductive structure is arranged and designed in such a way that, at least within an imaging volume of the magnetic-resonance

apparatus, a magnetic field of the structure, which is caused by a gradient field via induction effects, is similar to the gradient field. In this case, in one embodiment at least one part of the structure is designed in the form of a cask body as an integral part of a main field magnet. By this means, the gradient-coil system is, inter alia, capable of being designed without screening coils, since the consequences of the switched gradient fields, which are undesirable as such, can be fully controlled by a predistortion by reason of the similarity of the magnetic field that is caused by the structure.

Preferred embodiments of the present invention seek to create an improved gradient-coil system in which at least two structurally independent units of the gradient-coil system are arranged in such a way that a predeterminable spacing between the units can be accurately or exactly adjusted and permanently preserved.

According to an embodiment of the invention, there is provided a gradient-coil system having the features defined by Claim 1. Advantageous configurations are described in the dependent claims.

According to an embodiment of the present invention, the gradient-coil system includes the following features:

- at least two structurally independent units which contain at least the partial coils of the gradient coils of the gradient-coil system, and
- a support in which the units are secured, spaced from one another, for an antenna system which is capable of being arranged between them.

By virtue of the presence of the support, in which the units are secured in such a way that a free space having the predeterminable spacing arises between them,

handling - encompassing transportation, installation and removal - of the gradient-coil system as a whole is possible with little or no attention being required to be paid to the spacing that is to be exactly observed.

For a better understanding of the present invention, and to show how the same may be carried into effect, reference will now be made, by way of example to the accompanying drawings in which:

Figure 1 shows a longitudinal section through a gradient-coil system in which two structurally independent units containing the partial coils of gradient coils are fixed in a support with the aid of adjusting screws;

Figure 2 shows a longitudinal section through a gradient-coil system in which two structurally independent units containing the partial coils of gradient coils are secured in a support with the aid of an adhesive which has been introduced between the units and the support; and

Figure 3 shows longitudinal section through a magnetic-resonance apparatus incorporating a gradient-coil system according to Figure 1 or 2, which is secured in a cavity of a main field magnet that is bulged in the central region in the manner of a cask body.

Figure 1 shows, by way of an exemplary embodiment of the invention, a longitudinal section through a substantially hollow cylindrical gradient-coil system 100. In this embodiment, the gradient-coil system 100 comprises two structurally independent, hollow cylindrical units 112 and 114, each of said units 112 and 114 containing at least the partial coils of gradient coils of the gradient-coil system 100. Thus each of the units 112 and 114 contains two saddle-shaped

partial coils of a first transverse gradient coil, two further saddle-shaped partial coils of a second transverse gradient coil and one solenoid-type partial coil of a longitudinal gradient coil. In this case the units 112 and 114 are produced, for example, in accordance with the process described in DE 197 22 211 A1, which was cited in the introduction, by a conventional vacuum-casting method.

Furthermore, the gradient-coil system 100 comprises a support 120 which is produced from a glass-fibre-reinforced or carbon-fibre-reinforced synthetic material. The support 120 in this case contains a passive shim system, to which end the support 120 is formed with appropriate receiving apertures 129 for the insertion of shim supports 152 which are equipped with ferromagnetic shim elements 154. The laminar shim elements 154 are screw-coupled or adhesion-bonded to the shim support 152. In another embodiment, the shim elements 154 may also be inserted into receiving shim boxes.

On both sides of a central region in a region adjoining the units 112 and 114 the support 120 further exhibits bores 125 which are distributed both in the longitudinal direction and in the peripheral direction, with a thread for guiding adjusting screws 130. In this case, for each unit 112 and 114 at least three rows of bores 125 distributed in the peripheral direction are provided, each having three bores 125 arranged in a row. The units 112 and 114 are fixed in the support 120 with the aid of the adjusting screws 130. Via an initial torque of the adjusting screws 130, the fixing can be chosen from soft to hard, depending on the application of the gradient-coil system 100. As a result, a transmission of mechanical vibrations which emanate from the operated units 112 and 114 to the support 120 and further to other components of a magnetic-resonance apparatus in

which the gradient-coil system 100 is secured can be minimised. Each of the adjusting screws 130 comprises a threaded bolt 132 and a pressure plate 134, the pressure plate 134 comprising an insert 136 made of rubber or synthetic material.

With a view to transmitting high-frequency signals and receiving magnetic-resonance signals, a specially designed antenna system, for example, is provided for attachment between the two units 112 and 114. For this purpose, inter alia the two units 112 and 114 have to be adjusted in the longitudinal direction so as to be spaced exactly from one another by a predeterminable spacing dimension 149. To this end, in the central region of the support 120 at least three spacing strips 142 distributed in the peripheral direction are secured to the support 120, on which spacing strips the units 112 and 114 are arranged in contact on both sides with respect to the longitudinal direction, so that an exact spacing of the units 112 and 114 from one another is ensured, corresponding to the spacing dimension 149. Furthermore, for additional support in the longitudinal direction the two units 112 and 114 are fixed to the end faces of the support 120 by means of locking elements 144 which are secured to the support 120, for example by screwing. Finally, with respect to all the structural elements that are employed, but in particular in the case of the adjusting screws 130, the spacing strips 142 and the locking elements 144, attention has to be paid to a magnetic-resonance-compatible design - that is to say, in particular, to a design consisting of non-magnetic materials.

Figure 2 shows, by way of a further exemplary embodiment of the invention, a longitudinal section through another, substantially hollow cylindrical gradient-coil system 200. In this case the gradient-coil system 200 comprises two structurally independent units 212 and

214, each of the units 212 and 214 containing at least the partial coils of gradient coils of the gradient-coil system 200. Furthermore, the gradient-coil system 200 comprises a support 220 which is produced from a glass-fibre-reinforced and/or carbon-fibre reinforced synthetic material. In a central region of the support 220 four spacing strips 242 distributed in the peripheral direction are secured to the support 220, on which spacing strips the units 212 and 214 are arranged in contact on both sides with respect to a longitudinal direction, so that an exact spacing of the units 212 and 214 from one another with a spacing dimension 249 is ensured. Furthermore, for additional support in the longitudinal direction the two units 212 and 214 are fixed to the end faces of the support 220 by means of locking elements 244 which are secured to the support 220, for example by screwing. What has been described in the foregoing with reference to Figure 2 corresponds substantially up until now to what was described with reference to Figure 1.

Otherwise than in the case of Figure 1, however, in the case of the exemplary embodiment of Figure 2 the two units 212 and 214 are not connected to the support 220 with the aid of adjusting screws 130; rather, the two units 212 and 214 are secured within the support 220 by introducing an adhesive 260 between the surfaces of the two units 212 and 214 and of the support 220 facing directly towards one another. For introduction of the adhesive 260, which is in the liquid state of aggregation, in the region of the units 212 and 214 the support 220 exhibits, for each unit 212 or 214, four rows of, in each case, three bores 225 which are distributed in the peripheral direction. The adhesive 260 can be introduced via the bores 225 and the annular gap on the end faces of the gradient-coil system 200 between the units 212 and 214 and the support 220. In the course of an injection of the adhesive 260 via the

bores 225, spacings of less than 4 mm between the units 212 and 214 and the support 220 can be realised with advantage in a gradient-coil system 200 that has been designed for whole-body pictures of patients. In the case of larger spacings, filling is also possible exclusively via the aforementioned annular gap, so that the bores 225 can be dispensed with.

Potting compounds, for example comprising silicone, and other adhesives of the most diverse type, for instance also installation foams, can be employed by way of adhesive 260, in which connection both physically hardening adhesives for wet bonding, contact bonding, activation bonding and pressure-sensitive bonding and also chemically hardening adhesives for reaction bonding, comprising chemically curing adhesives, for example a curing resin, are suitable.

Furthermore, an adhesive with a melting-temperature approximately between 50 °C and 90 °C, for example a wax or a similarly low-melting material, can also be used by way of adhesive 260. In normal operation of the gradient-coil system 200, by appropriate control of the currents in the partial coils and by appropriate control of a cooling unit which is optionally present in the gradient-coil system 200 it is ensured that a temperature on the outer cylindrical casing of the units 212 and 214 is sufficiently distant from the melting-temperature of the wax that is being used. For non-destructive removal of the units 212 and 214 from the support 220, the outer casing of the units 212 and 214 merely has to be heated to a temperature above the melting-point of the adhesive 260 that is being employed. To this end, appropriate currents in the partial coils can be adjusted. In another embodiment, the gradient-coil system 200 is provided with an additional heating device. By this means, the possibility is opened up of being able to install and

remove the units 212 and 214 in reversible and non-destructive manner.

Finally, Figure 3 shows, by way of a further exemplary embodiment of the invention, the use of one of the gradient-coil systems 100 or 200 described in the foregoing in a magnetic-resonance apparatus having a main field magnet 310, the cavity of which is bulged in the form of a cask body in a central region and is of cylindrical design in marginal regions which adjoin both sides of the central region. In this connection, the main field magnet 310 is configured, for example, in accordance with DE 101 56 770 A1, which was cited in the introduction. In the cavity of the main field magnet 310 one of the gradient-coil systems 100 or 200 is integrated for the purpose of generating gradient fields. For the purpose of transmitting high-frequency signals and receiving magnetic-resonance signals, a specially designed antenna system 320 is arranged between the two units 112 and 114 or 212 and 214 of the gradient-coil system 100 or 200. In this connection, the gradient-coil system 100 or 200 is secured in the cavity by means of wedges 350, for example in accordance with DE 197 22 481 A1, which was cited in the introduction. In another embodiment, the gradient-coil system 100 or 200 is secured in the main field magnet 310 in a manner as described in connection with Figure 2 for the attachment of the units 212 and 214 in the support 220. In this case, the design of the gradient-coil system 100 or 200 comprising two structurally independent units 112 and 114 or 212 and 214 with the common support 120 or 220 enables a simpler attachment in the cavity which is bulged in the central region in the manner of a cask body than would be possible for the two units 112 and 114 or 212 and 214 without the support 120 or 220.

List of Reference Symbols

100, 200	gradient-coil system
112, 114, 212, 214	unit
120, 220	support
125, 225	bore
129	receiving aperture
130	adjusting screw
132	threaded bolt
134	pressure plate
136	insert
142, 242	spacing strip
144, 244	locking element
149, 249	spacing dimension
152	shim support
154	shim element
260	adhesive
310	main field magnet
320	antenna system
350	wedge

Claims

1. A gradient-coil system comprising:
- at least two structurally independent units which contain at least the partial coils of the gradient coils of the gradient-coil system, and
- a support in which the units are secured, spaced from one another, for an antenna system which is capable of being arranged between them.

2. 2. Gradient-coil system according to Claim 1, wherein the units and/or the support is/are of hollow cylindrical design.

3. Gradient-coil system according to one of Claims 1 or 2, wherein the units and/or the support is/are of potted design.

4. Gradient-coil system according to one of Claims 1 to 3, wherein the support contains a shim system.

5. Gradient-coil system according to one of Claims 1 to 4, wherein the support comprises a composite material.

6. Gradient-coil system according to Claim 5, wherein the composite material is a glass-fibre-reinforced or carbon-fibre-reinforced synthetic material.

7. Gradient-coil system according to one of Claims 1 to 6, wherein spacing means are arranged between the units for the purpose of precise spacing of the units from one another.

8. Gradient-coil system according to Claim 7, wherein the spacing means are secured to the support.

9. Gradient-coil system according to one of Claims 7 or 8, wherein the spacing means comprise at least three spacing strips which are distributed in a peripheral direction of the support.

10. Gradient-coil system according to one of Claims 1 to 9, wherein locking means are secured to the support for the purpose of securing the units in the direction of spacing.

11. Gradient-coil system according to Claim 10, wherein the locking means are secured to at least one end face of the support.

12. Gradient-coil system according to one of Claims 10 or 11, wherein for each end face of the support the locking means comprise at least three locking elements which are distributed in a peripheral direction of the support.

13. Gradient-coil system according to one of Claims 1 to 12, wherein the units are connected to the support with the aid of adjusting screws which are guided in the support.

14. Gradient-coil system according to Claim 13, wherein for each unit at least three rows of adjusting screws with at least three adjusting screws per row are provided.

15. Gradient-coil system according to Claim 14, wherein the rows are distributed in a peripheral direction of the support.

16. Gradient-coil system according to one of Claims 13 to 15, wherein one of the adjusting screws comprises a threaded bolt and a pressure plate with an insert made of a soft material.

17. Gradient-coil system according to Claim 16, wherein the material comprises a rubber or a synthetic material.

18. Gradient-coil system according to one of Claims 1 to 17, wherein the units are secured by an adhesive which has been introduced between the units and the support.

19. Gradient-coil system according to Claim 18, wherein the support has apertures for the purpose of introducing the adhesive.

20. Gradient-coil system according to Claim 19, wherein for each unit at least three rows of apertures with at least three apertures per row are provided.

21. Gradient-coil system according to Claim 20, wherein the rows are distributed in a peripheral direction of the support.

22. Gradient-coil system according to one of Claims 18 to 21, wherein the adhesive comprises silicone, a foam and/or a resin.

23. A magnetic-resonance apparatus incorporating a gradient-coil system according to one of Claims 1 to 22.

24. Magnetic-resonance apparatus according to Claim 23, wherein the gradient-coil system is secured in a cavity of the magnetic-resonance apparatus that is bulged in a central region in the manner of a cask body.

25. Magnetic-resonance apparatus according to one of Claims 23 or 24, wherein the antenna system which is secured to the units is arranged between the units.

26. A gradient-coil system substantially as herein described with reference to the accompanying drawings.

27. A magnetic-resonance apparatus substantially as herein described with reference to the accompanying drawings.

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Application No:	GB 0323242.8	**Examiner:**	Peter Davies
Claims searched:	1	**Date of search:**	15 April 2004

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	1 at least	US 5729141	(INTERMAGNETICS) - coil sections 58A and 58B plus excitation coils 70 of figure 17.
X	1 at least	EP 1271172	(PHILIPS) - paragraphs 16 to 18 especially, noting gradient coil systems 3 and 5 and excitation coil 11 of fig. 1.
X, E	1 at least	US 2003/0016015	(PHILIPS) - an English translation of EP 1271172.
X	1 at least	US 5414360	(BRUKER) - note figures 1, 4, 7 and 8 showing gradient coils 14 and 15 and rf coil 100.
X	1 at least	US 5576623	(BRUKER) - gradient systems 14, 24, 34 or 44.
X	1 at least	US 5200701	(SIEMENS) - column 3 and figure 1.
X	1 at least	US 4636729	(SIEMENS) - note pairs of gradient coils in figure 1.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{W}:

G1N

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

G01R

The following online and other databases have been used in the preparation of this search report:

EPODOC, WPI, JAPIO, INSPEC